



Extending the Life of IoT Devices with Energy-Harvesting Solutions

Organization

- STMicroelectronics with French university Ecole Supérieure d'Electronique de l'Ouest (ESEO)

Challenges

- Extend IoT Device battery life via "energy harvesting", transforming RF energy into DC power
- Design an impedance-matching circuit to charge IoT device batteries from antenna-harvested, rectified DC power
- Designers needed concurrent modelling for linear and non-linear components

Solutions

- Keysight ADS software provided accurate linear and non-linear co-simulation, resulting in a more efficient design
- Minimized parasitics using diode package models

Results

- Met design goals: achieved 13% efficiency at DC power threshold of -20 dBm
- Achieved 68% efficiency at +20 dBm input power
- Minimized return loss by tuning distance between matching capacitor and SMA connector

Many of the devices destined for the Internet of Things (IoT) aim to fulfill the promise of a more efficient and connected world. Many devices are expected to operate for several years with no updates, no recharging, and no human intervention.

There are three ways to address the energy needs of power-hungry IoT devices:

1. Optimize the device for power consumption
2. Increase the size of the device battery
3. Continuously charge the device battery to extend longevity

Transforming electromagnetic (EM) radiation into electrical power is a promising solution for extending IoT battery life. Harvesting microwave band radiation (2.45 GHz Wi-Fi signals) provide a new source of energy to address the power issue.

In Europe, Geneva-based STMicroelectronics and French university Ecole Supérieure d'Electronique de l'Ouest (ESEO) collaborated on the development of "energy harvesting" circuits capable of transforming RF energy into DC power. The core of the design includes an antenna and a rectifier working together to capture the low-level energy. The antenna intercepts some of the power to produce an electric current and the rectifier converts the current from AC to DC. However, the low-impedance signals from the antenna are insufficient to drive the high-impedance requirements of the rectifier diode. STMicroelectronics and ESEO needed a design that could create sufficient voltage levels to charge the onboard batteries.

The Challenge: Matching Impedances and Transforming Voltages

The energy-harvesting circuit, antenna, and rectifier design included a Schottky diode, a load resistor, an input-matching circuit, and an output-bypass capacitor. Antennas typically have impedance ratings that are tens of ohms, while the diodes providing rectification have an impedance of several kilo-ohms. A large impedance transformation is required, and the design of the input matching circuit must also deliver on the forward voltage drop requirements of the diode, typically 0.2 to 0.4 volts. All of this must be accomplished in a circuit where the antenna typically gathers less than a microwatt of power, and in a system where impedance of the diode varies with the amplitude of the input voltage.

The Solution: Using Co-simulation to Optimize a Rectifying Circuit

Electronic design automation (EDA) tools help designers solve these challenges by fully optimizing the rectifying circuit. STMicroelectronics and ESEO chose Keysight Advanced Design System (ADS) and its co-simulation capabilities to accurately design and simulate the rectifying circuit for the energy harvesting solution.

Co-simulation enables designers to create models of physical parts and add them to a circuit simulation. In this case, the designers used the co-simulation features of ADS to optimize the antenna/rectifier design. The ADS Momentum 3D planar field solver was used to perform passive modeling and analysis of the rectifying circuit.

The designers also simulated the circuit in the frequency-domain with the ADS Harmonic Balance circuit solver. Unlike AC analysis in a generic Simulation Program with Integrated Circuit Emphasis (SPICE) tool, Harmonic Balance accounts for the nonlinear characteristics of the diode. For the energy harvester, the developers included diode package models to understand and minimize parasitic effects in the circuit. This enabled STMicroelectronics and ESEO to achieve good correlation between simulated and measured results.

The Results: Creating a Successful Energy-Harvesting System

With this combination of tools, the design team successfully created an energy-harvesting system that transformed ambient 2.45-GHz wireless signals into DC power. In addition to designing and simulating an optimized rectifier, the tool also helped optimize the physical distance between the matching capacitor and the SubMiniature version A (SMA) connector (Figure 1; see arrow “d”). Optimizing the physical distance between the connector and capacitor further reduced the return loss of the rectifier.

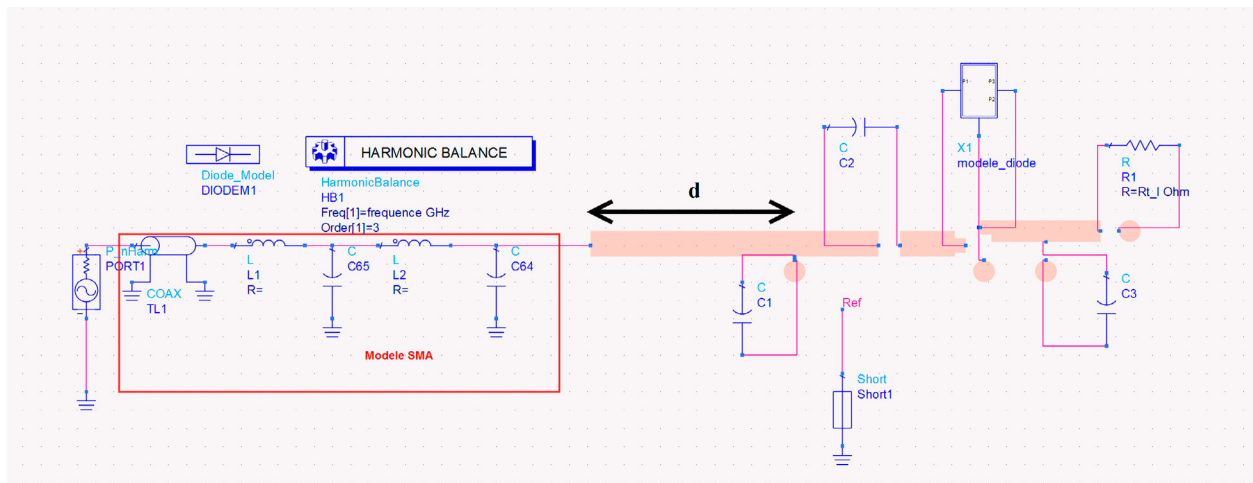


Figure 1. Using Keysight’s circuit simulation tool (ADS) to optimize the distance between the internal matching capacitor and the external SMA connector

To test and validate the antenna/rectifier system, the team used a variety of patch antennas. Through experimentation and simulation, they concluded that an antenna with an equiangular spiral pattern resulted in optimal performance.

In outdoor testing, this design produced usable DC power at a threshold value of -20 dBm with estimated efficiency of 13 percent. During testing, using a calibrated source in an anechoic chamber, the design delivered a maximum efficiency of 68 percent at an input power of $+20$ dBm (Figure 2). The tests show good correlation with their simulation results, and met the team’s voltage and efficiency design goals, overcoming the initial design challenges of transforming the impedances.

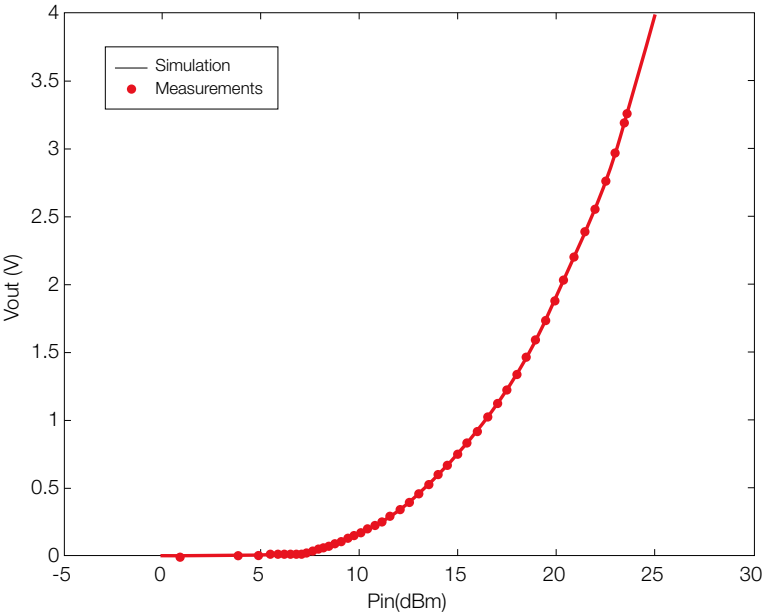


Figure 2. STMicroelectronics and ESEO show good correlation between their simulation and measurement results of the RF signal to DC power

Going Forward

In the future, billions of IoT devices will proliferate in a variety of environments blanketed by ambient RF energy: office buildings, hotels, factories, warehouses, homes, connected cars, and more. STMicroelectronics and ESEO provided a great example of the technique of “energy harvesting”, designing circuits capable of transforming RF energy into DC power. They overcame challenges to create a design with sufficient voltage levels to charge the onboard batteries. With their EDA tool, they fully optimized the circuit; ensuring the antenna and rectifier work together to capture the low-level energy and create enough voltage. With the ongoing proliferation of wireless networks and IoT devices, further refinement of “energy harvesting” will become increasingly valuable for designs that are expected to operate unattended for several years without maintenance, recharging, or human intervention.

Related Information

- Brochure: *Keysight EEsof EDA Advanced Design System*, publication 5988-3326EN
- Brochure: *Keysight EEsof EDA Momentum*, publication 5990-3633EN
- Brochure: *Keysight EEsof EDA W2300 Harmonic Balance Element*, publication 5990-3808EN
- Bouchouicha, Dhaou & Latrach, Mohamed & Dupont, François & Ventura, L. (2010). *An experimental evaluation of surrounding RF energy harvesting devices*.
- ZBITOU, JAMAL & Latrach, Mohamed & Toutain, Serge. (2006). *Hybrid rectenna and monolithic integrated zero-bias microwave rectifier*. Microwave Theory and Techniques, IEEE Transactions on. 54. 147 - 152. 10.1109/TMTT.2005.860509.

www.keysight.com/find/ADS